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RECENT DEVELOPMENTS IN DAIRY CATTLE NUTRITION 1/

L. A. Moore 2/

Two recent developments in dairy cattle nutrition at Beltsville, Md., have practical as well as fundamental significance. The first concerns recent progress in understanding the energy metabolism of dairy cattle, including efficiency of feed utilization and methods of expressing the energy values of feeds. The second concerns the development of new chemical methods for the analysis of feeds, particularly forages. W. P. Flatt has been concerned with the energy studies and P. J. Van Soest has been involved in the methods of forage analysis. Both are scientists of the dairy cattle nutrition laboratories of the Animal Husbandry Research Division at Beltsville.

NET ENERGY STUDIES

To feed animals the necessary energy on a practical basis, guides are essential. The guides must express the energy requirements for maintenance, growth, fattening, and milk production; they must express the energy values of common feeds for meeting the requirements in the same units. In the United States total digestible nutrients (TDN) or digestible energy (DE) are used as guides. In Europe the net energy (NE) concept, or some modification of this concept such as starch equivalent, has been used. Some nutritionists have discussed the possible use of metabolizable energy (ME) for calculating rations for large animals.

Methods of Expressing Energy Value of Feeds

The two major systems of expressing energy values of feeds are shown in table 1, as taken from the highest to the lowest energy values of Morrison's Feeds and Feeding (9) 3/.

1/ Presented at the Arkansas Formula Feed Conference, Fayetteville, Ark., September 24, 1965.

2/ Animal Husbandry Research Division, Agricultural Research Service, USDA, Beltsville, Md.

3/ Underscored figures in parentheses refer to Literature Cited at end of publication.

TABLE 1.--Relative values of feeds expressed on a total digestible nutrient (TDN) and an estimated net energy (ENE) basis 1/

Feeds	TDN	ENE	ENE as percent of TDN
	Percent lb. per 100 lb.	Therms per 100 lb.	Percent
Corn	80.1	80.1	100.0
Sorghum (grain)	79.9	77.8	97.3
Barley	77.7	70.5	90.7
Oats	70.1	65.7	93.7
Brewers grain	67.1	60.4	90.0
Bran	66.9	56.9	85.1
Screenings	62.8	53.4	85.0
Alfalfa (very leafy)	52.7	43.5	82.5
Alfalfa (all analyses)	50.7	40.6	80.1
Alfalfa (stemmy)	46.3	33.3	71.9
Oat straw	44.8	23.3	52.0
Wheat straw	40.6	10.1	24.6

1/ Source: Taken from tables 1 and 2 (9).

Table 1 shows that the TDN and the ENE values for the concentrates generally agree with each other; but, as the TDN or energy content of the feeds decreases, there is an increasing divergence (100 to 24.6 percent) in the values. This is expressed in the column ENE as percent of TDN. The principle of gradual divergence as related to energy concentration is presented in the discussion on net energy values of feeds. Obviously, both sets of values cannot be correct, particularly in comparing forages and concentrates or forages differing widely in digestibility.

Early Experiments at Beltsville

During the period 1946-55, many individual trials were conducted at Beltsville where corn was substituted for alfalfa hay on either a TDN or ENE basis. The cows were placed on an all-alfalfa hay ration at calving and were used in the experiments after energy intake and energy requirements had come into equilibrium with each other as indicated by constant body weight, milk production, and feed intake. This usually occurred 6 to 8 weeks post partum. At this stage cows are very responsive in terms of change in level of milk production to different levels of energy.

The results of a typical trial out of some 60 trials are shown in table 2.

TABLE 2.--Effect on milk production of replacing alfalfa hay with corn on a TDN basis 1/

Item	10-day periods 1	2	3
Alfalfa........................pounds.......	25.6	16.9	24.9
Corn...........................pounds.......	--	5.4	--
Total TDN......................pounds.......	13.0	12.9	12.6
Total NE.......................therms.......	10.4	11.2	10.1
FCM 2/ produced................pounds.......	24.4	26.5	24.4
FCM diff......................percent.......	--	3/+8.6	--
TDN diff......................percent.......	--	3/+0.8	--
ENE diff......................percent.......	--	3/+9.3	--

1/ TDN and ENE values taken from tables 1 and 2, Morrison's Feeds and Feeding (9). Alfalfa hay at 50.1 percent TDN, 40.6 percent ENE. Corn at 80.1 percent TDN and ENE.

2/ FCM = 4 percent fat corrected milk.

3/ Based on the average of period 1 and 3.

In the second 10-day period of this trial, 5.4 lb. of corn was substituted for 8.4 lb. of alfalfa hay. There was only a calculated increase of 0.8 percent in TDN but an 8.7 percent increase in ENE intake. Since FCM production increased 8.6 percent, it is obvious that the net energy concept expressed differences in feeding value much more accurately. It also demonstrated that energy expressed as TDN is used more efficiently from some feed sources than from others.

Similar results have been found based on studies conducted in cooperation with the laboratories at Beltsville (12, 14) and based on other independent work (7, 13). Despite the strong circumstantial evidence of weakness in the TDN system of expressing the energy value of feeds, nutritionists have clung to it. However, this attitude is understandable since the NE values used in the previous studies were not determined. The values were calculated from chemical composition data or from TDN values.

Recent Energy Studies at Beltsville

Because of the above disagreement among scientists and the lack of precise information during the period around 1950 and the fact that the problem was of considerable economic significance, an energy metabolism laboratory was established at Beltsville.

After some preliminary studies, the first experiment was begun in 1962. The primary purpose was to determine the efficiency of utilization of ME from rations containing varying forage to concentrate ratios. Whereas the ME of a feed is an improved measure of the nutritive value over TDN or DE, since it takes into account urinary and methane losses, it does not take

into account the large and variable losses due to heat increment. Therefore, if there are differences in the utilization of ME from different feed sources, these differences would be further magnified if expressed on a TDN or DE basis. In energy studies ME is more logical to use, therefore, the results were expressed on the efficiency of utilization of ME. Many nutritionists have believed that once the energy, in the form of volatile fatty acids, amino acids, and so forth, has passed through the gut wall, it was utilized with equal energetic efficiency regardless of its original source. This was also one of the questions involved.

Six cows were fed three rations during various period of lactation. The rations on a dry-matter basis consisted of 100 percent alfalfa hay (C), 75 percent alfalfa hay and 25 percent concentrate (B), and 50 percent alfalfa hay and 50 percent concentrate (A) (3). Energy balances were determined during three stages of lactation and during the dry period.

The key results as published (3) are shown in table 3.

TABLE 3.--Efficiency of utilization of metabolizable energy

Ration	Alfalfa as dry matter	Gross energy consumed	Total heat production	ME consumed	Efficiency of utilization of ME available for lactation
	Percent	Mega-calories	Mega-calories	Mega-calories	Percent
C	100	71.6	24.6	36.6	54
B	75	68.7	23.6	37.3	61
A	50	61.7	22.1	36.6	65

It can be seen from table 3 that of the ME available for milk production, ration C (all alfalfa) was utilized with an efficiency of 54 percent and rations B and A were utilized with efficiencies of 61 and 65 percent, respectively. Calculation of the same data on an NE-basis showed that the same amount of NE was required to produce a pound of milk irrespective of the composition of the ration. Thus, ration composition has a marked effect on the utilization of ME. It must be concluded that NE is the only valid method for expressing the energy value of feeds.

Some other observations were also made during these experiments, which are of considerable importance in terms of interpretation of previous feeding studies.

Depression of Digestibility

It has recently been suggested (11) that the addition of increasing amounts of concentrates in forage rations causes a depression of digestibility of the ration. From this observation it has been reasoned that more energy would be required to produce a pound of milk as the level of concentrate feeding increased. The experiments conducted at Beltsville show some depression of digestibility as the level of concentrate feeding within a ration increased. However, the results also showed that there were lower losses of energy in the form of methane and urine, which offset the lowered digestibility, so that within the respective rations the same amount of ME was required to produce a pound of milk regardless of the level of feeding.

Body Composition Changes

The data collected at Beltsville also demonstrated that there can be considerable loss of body energy or fat in the early stages of lactation without apparent weight changes. Loss of body weight may not be evident because of increased daily feed intake with resulting fill and retention of body water when fat is being mobilized. If such took place during the so-called practical input-output experiments, it would lead to gross misinterpretation of the data. Such has apparently happened in the past and has led to erroneous conclusions in the TDN and NE controversy.

Efficiency of Fattening

Recent data in the literature (2, 6) indicate that fattening during lactation may be more efficient than during the dry period. The preliminary results obtained in the energy studies at Beltsville confirm the above observations. If this is true, it would be more efficient to build up body reserves of energy (fat) during the latter part of the lactation period than during the dry period, as is the present practice.

Net Energy Values of Feeds

The lack of a sufficient number of determined energy values of feeds has been used as an argument against the use of NE system of feed evaluation. From a practical standpoint, this is a weak argument. In table 1 the principle of gradual divergence of NE values was noted, as the concentration of TDN in the feed decreased. From this relationship, a regression equation was developed using actually determined NE (Y) and TDN (X) values of the same feed. The regression $Y = 1.45X - 38.83$ was calculated (8) from data published by Forbes (5). Thus, approximate NE values can be calculated from the TDN value of the feed, which are sufficiently accurate for practical feeding purposes. To use the regression equation, the determined TDN values are placed on a dry-matter basis, and the resulting NE values calculated to a DM-basis from the equation. This equation was used to calculate the values in United States Department of Agriculture Farmers' Bulletin No. 2153 entitled, "Feeding Dairy Cattle," (1). Thus, it is possible to use the NE values calculated from the TDN values when the relationship between these values is understood. The ENE values of feeds also can be obtained from Morrison's publication (9).

Efficiency of Utilization of Energy for Different Functions

Another argument usually advanced against the use of NE values of feeds has been that the values vary when the energy is used for different physiological functions, such as maintenance, fattening, growth and lactation. Except for fattening, NE is utilized for the other functions from a practical standpoint with about equal efficiency. If fattening during lactation is as efficient as preliminary data indicate, this would not pose a problem. This leaves fattening without lactation a problem. A very simple answer to this problem would be to artificially increase the NE requirements for fattening to a point where the calculated efficiency would equal that for the other functions, or vice versa. Thus, the same NE values for feeds could be used for all functions.

NEW CHEMICAL METHODS FOR ANALYSIS OF FEEDS

The Weende system of proximate analysis is an attempt to evaluate the feeds by using chemical methods. Protein (N X 6.25), ash, crude fiber (CF), fat and dry matter are determined. Nitrogen-free extract (NFE) is calculated by difference. This division of the carbohydrate fraction (CHO) into CF--supposedly the indigestible and insoluble fraction--and the NFE--supposedly highly digestible soluble fraction--is not a truly realistic nutritional separation because the separation does not accomplish what was intended. The CF fraction is the residue of the feed left after treatment with a weak alkali and a weak acid.

Digestibility and Composition of CF and NFE

The digestibility of the CF and NFE of feeds is shown in table 4.

TABLE 4.--Relative digestibility in percent of crude fiber (CF) by the Weende method and nitrogen-free extract 1/

Feed	Number of digestibility trials	Average digestibility		Percent cases with as high digestibility for CF as for NFE
		CF	NFE	
Dry feed	110	52.4	59.5	30
Succulent feed	61	63.5	76.3	20
Silage	25	58.2	64.6	28
Concentrates	88	53.3	78.5	10

1/ From (4).

In 30 percent of the cases of dry feed the CF or insoluble fraction was as digestible as the NFE or soluble fraction. The principal reason for this result is that lignin, an indigestible constituent of feeds, is partly soluble in weak alkali and, therefore, goes into the NFE fraction. This is illustrated in table 5.

TABLE 5.--Composition of crude fiber (CF) and nitrogen-free extract (NFE) and distribution of constituents in CF and NFE 1/

Feed and constituent	Composition		Distribution of Constituents	
	CF percent	NFE percent	CF percent of total	NFE percent of total
STRAW (OAT):				
Lignin	7.0	19.0	28.5	71.5
Cellulose	83.8	31.0	74.2	25.8
Pentosans	11.6	45.6	21.2	78.8
Total	102.4	95.6		
HAY (CLOVER AND GRASS):				
Lignin	11.5	9.8	40.6	59.4
Cellulose	80.1	20.5	69.3	30.7
Pentosans	11.0	29.4	17.6	82.3
Total	102.6	59.7		

1/ From (10).

It can be seen from the last column of the table that for oat straw 71.5 percent of indigestible lignin was present in the NFE or the supposedly highly digestible fraction. Therefore, it must be concluded that the determination of CF using proximate analyses methods is not nutritionally realistic.

Development of New Methods

Despite the fact that this inconsistency as pointed out above has been known for a long time and despite the fact that since 1925 many chemists have tackled the problem, no system to replace CF and NFE was adopted. We began intensive work on this problem at Beltsville 15 years ago. Only during the last 3 years has the problem yielded to this intensive effort.

The approach has been to divide the carbohydrate (CHO) fraction into cell contents, or the soluble, highly digestible constituents, and into the cell wall fraction, the insoluble and partly indigestible constituents. This division as proposed is comparable to that made in the digestive tract but has made use of detergents and chelating agents which were not available to the early workers.

Cell Contents and Cell Wall Constituents

The division of CHO fraction into cell contents or soluble fraction and cell wall constituents or insoluble fraction is accomplished through treatment of the feed with a neutral detergent solution of sodium lauryl sulfate at pH 7 (16). The fraction dissolved out of the feed is called cell contents, which is almost completely digestible. The residue is termed cell walls or neutral detergent fiber. Another original sample treated with an acid solution of cetyltrimethylamonium bromide which dissolves out the hemicelluloses as well as the cell constituents and leaves the acid detergent fiber which contains cellulose and the associated lignin (15). The schematic division is shown in table 6.

TABLE 6.--Division of forage organic matter by system of analysis using detergent

Fraction	Components	Characteristic
Cell contents (soluble in neutral detergent)	Lipids	Almost completely digestible--not lignified.
	Sugars, organic acids and water-soluble matter	
	Pectin	
	Starch	
	Non protein nitrogen	
	Soluble protein	
Cell-wall constituents (fiber insoluble in neutral detergent)		Partly digestible according to the degree of lignification.
(1) Soluble in acid detergent	Hemicellulose	
	Fiber-bound protein	
(2) Insoluble in detergent (acid detergent fiber)	Cellulose	
	Lignin	
	Lignified nitrogen compounds	

This method of separation appears to bear some resemblance or similarity to that which takes place in the digestive tract in contrast to the separation into CF and NFE. Work is now in progress to adapt the methods to feeds which contain starch such as concentrates.

Equation for Predicting Digestibility of Feeds

During the progress of this project, equations have been developed for predicting digestibility by utilizing values obtained for the various fractions as determined by the newly developed methods. The latest equation, termed the summative equation, shows considerable promise. The equation is:

$$\text{Digestible dry matter} = 98S + W(147.3 - 78.9 \text{ Log } L) - 12.9$$

where S = percentage of cell contents
W = percentage of cell walls
L = percentage of lignin in acid detergent fiber

This equation was developed from a group of 19 forages consisting of 6 bromegrasses, 4 orchardgrass, 1 timothy, 6 alfalfa, 1 red clover, and 1 soybean hay. The equation was then applied to a second group of 30 forages consisting of 6 orchardgrass, 5 ryegrass, 1 Reed canarygrass, 3 bermudagrass, 9 alfalfa, 3 lespedeza, and 3 trefoil forages. The correlations and the standard deviation used in the equation are shown in table 7.

TABLE 7.--Correlations and standard deviations of calculated and determined digestibility

Item	Group 1 1/	Group 2 2/
Correlation..................................	0.96	0.93
Standard deviation from regression.............	2.8	2.9
Standard deviation of differences..............	2.7	3.7

1/ Composed of 19 forages used to derive equation.

2/ Composed of 30 forages used to prove the equation.

From the table it will be noted that a high correlation of 0.93 was obtained when the equation was applied to 30 forages not used in developing the original equation. This correlation is very high and the standard deviation would be comparable to the standard deviation obtained in actual digestibility trials. Furthermore, the correlation is a great improvement over that using proximate constituents to predict digestibility.

Composition of Some Feeds

The different fibers and the lignin values of some common feeds are shown in table 8.

TABLE 8.--Composition of some feedstuffs as percent of dry matter

Feedstuff	NDF 1/	ADF 2/	Lignin	CF 3/	Digestibility
Soybean hulls	60.9	43.7	--	35.4	--
Soybean meal (extract)	--	9.0	0.3	5.9	--
Corn grain	10.5	3.2	--	2.2	--
Oats	--	18.2	3.8	4/12.1	--
Peanut meal	17.0	8.1	1.3	4/6.9	--
Dried beet pulp	--	31.4	1.1	4/19.6	--
Citrus pulp	--	20.6	1.2	4/11.6	--
Cooked poultry feathers	77.9	20.0	--	1.5	82 5/
Raw poultry feathers	88.1	68.2	--	1.3	17 5/
Orchardgrass early cut	52.3	27.1	2.7	24.1	72
Alfalfa hay early cut	40.2	25.1	5.3	23.5	62
Orchardgrass late cut	70.4	40.1	4.7	35.0	57
Alfalfa hay late cut	55.2	39.5	8.7	38.6	53
Wheat straw	81.8	53.3	7.6	42.4	21

1/ NDF = neutral detergent fiber (cell wall constituents)

2/ ADF = acid detergent fiber.

3/ CF = crude fiber.

4/ Values from Morrison (9).

5/ Pepsin digestion.

It will be noted that the acid detergent fiber and crude fiber figures are similar, with the crude fiber figures covering a more narrow range. The neutral detergent fiber (NDF) figures are larger than the acid detergent fiber (ADF) and CF since the hemicellulose is included with the cellulose and lignin. In comparing orchardgrass early cut and alfalfa hay early cut, the crude fiber figures are almost identical 24.1 to 23.5 respectively, yet the lignin content of the alfalfa is about twice as large and the digestibility 10 units less. It is also interesting to note the relationship between the ADF and digestibility of raw and cooked poultry feathers. Thus, the new "fiber" values also bear some relationship to the digestibility of animal products.

SUMMARY

(1) It seems obvious and clear-cut that the net energy system of feed evaluation should be used in feeding ruminants.

(2) It is possible to calculate approximate net energy values from determined total digestible nutrient (TDN) values.

(3) New chemical methods for the fractionation of the carbohydrates of forages have been developed which are nutritionally realistic.

(4) Through the use of a newly developed equation, digestibility of forages can be predicted with reasonable accuracy.

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